Physics 51 LECTURE 2 September 30, 2011

Estimates: galaxies in the universe; heartbeats in a lifetime

Dimensional analysis: Planck length and mass

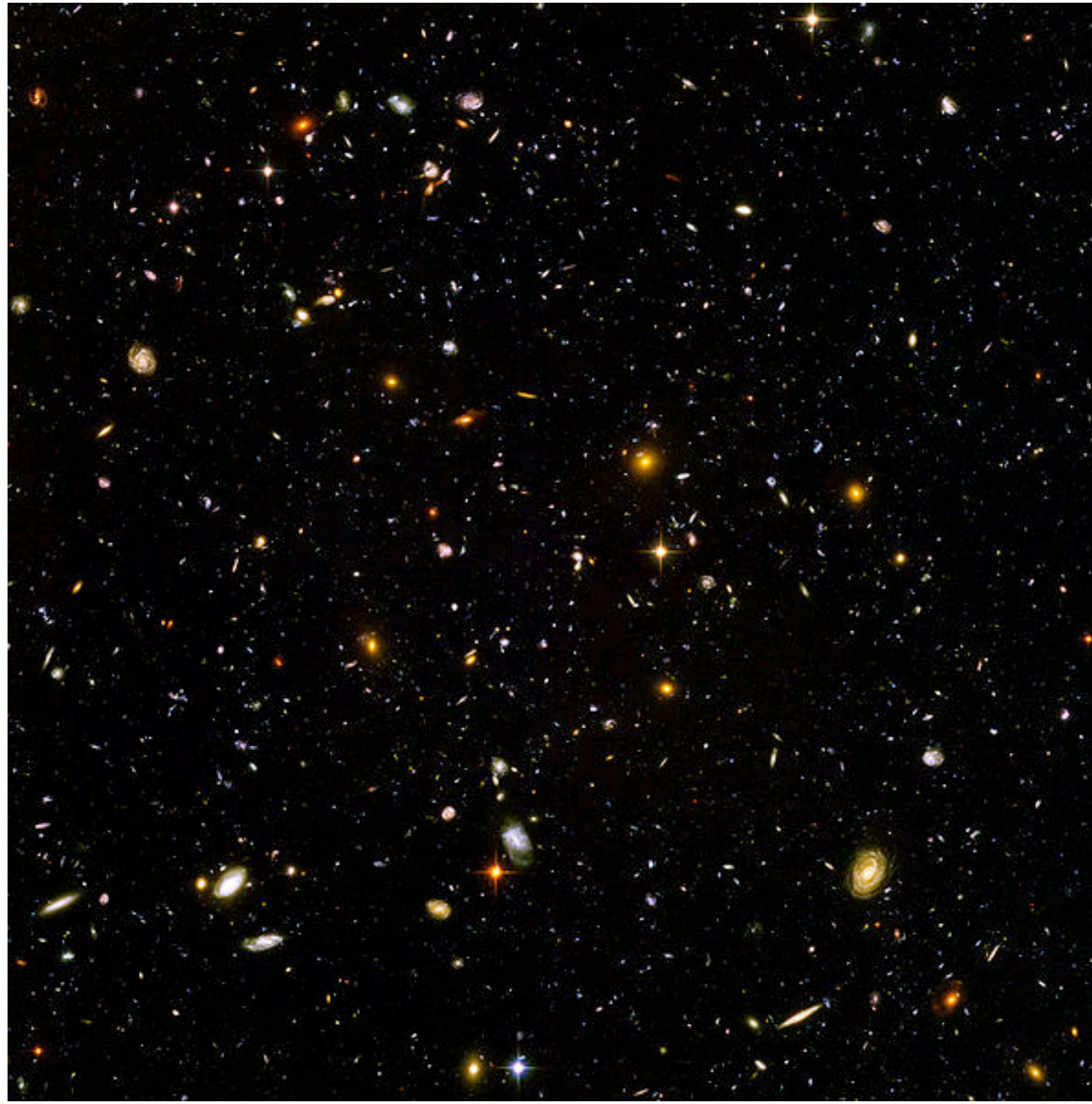
Sizes in the universe: Cosmic Uroboros

Kinematics using calculus: vectors add

Newton's Laws
1. inertia — inertial reference frames
2. F/a = mass — is a property of matter
3. $F_{ab} = - F_{ba}$ — momentum conservation

NOTE: Next Physics 51 class is Monday October 10 in ISB 231 at 11:00-12:10 (same class, same time, but different day!)

How many galaxies are there in the Universe?



The Hubble Ultra Deep Field contains about 10,000 galaxies. It covers only about 1/50 the area of the full moon, so the whole sky covers about 13,000,000 times as much area. Thus the total number of galaxies in the universe is about 10,000x13,000,000 = 130,000,000,000 or 130 billion.

All the stars, gas, dust, and everything else we can see add up to only about 0.5% of the cosmic density. There is about 10x more invisible atoms, so the total is about 5%. Most of the cosmic density is invisible cold dark matter (about 23%) and dark energy (72%).

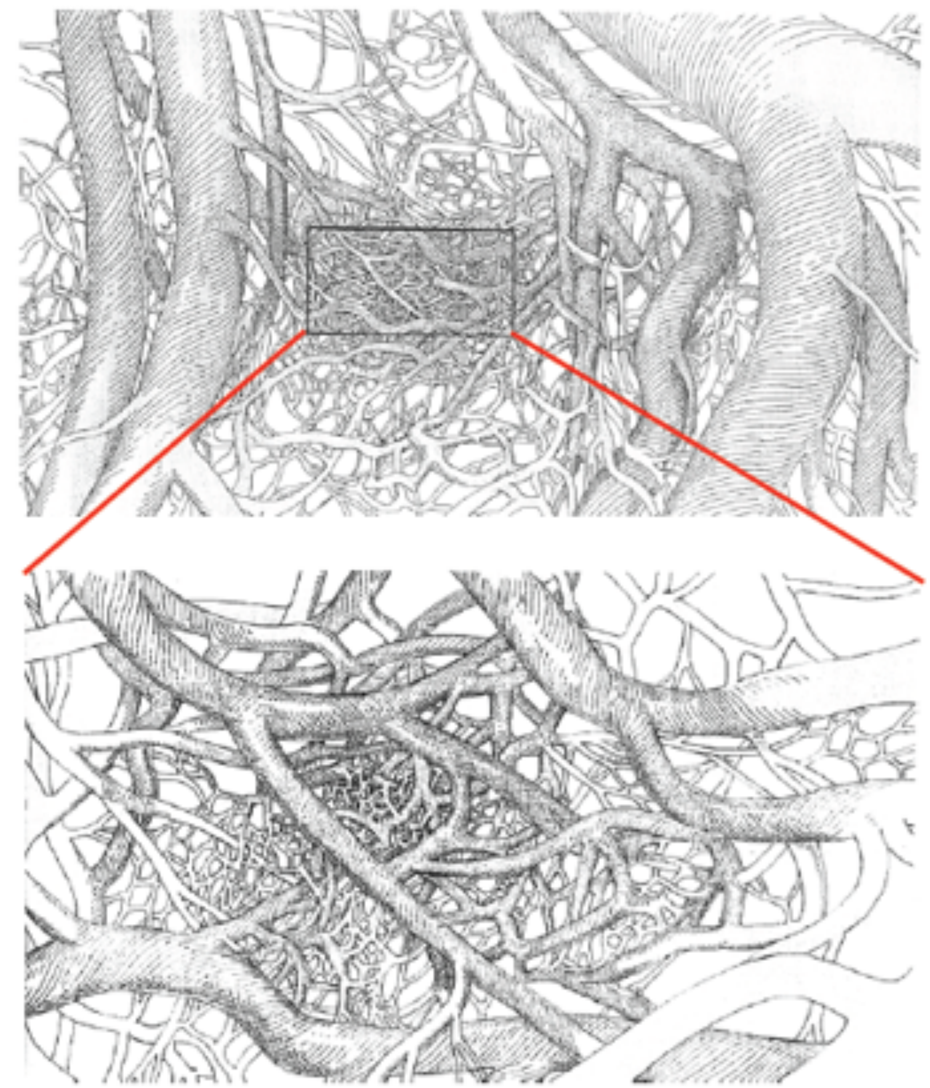
About a Billion Heartbeats in a Lifetime

Cells of *all* plants and animals on Earth are about 10^{-3} cm – regardless of the size of the plant or animal. Since every cell needs nutrients, any large organism needs a circulatory system to get the nutrients to the cells and carry away the cells' wastes. The circulatory system is basically a network of tubes where each branch branches, and each of those branches again, down to the tiniest capillaries that supply individual cells. No matter what size scale you zoom in on, from the largest arteries to the smallest capillaries, the circulatory system looks pretty much the same. Any object that looks the same across size scales is called a "fractal."

All biological circulatory networks must reach every single cell (or the unreached cells will die), and evolution insures that they do so using the minimum possible energy to circulate the blood. A fractal is the only structure that can satisfy both conditions.

A consequence is that each cell in larger organisms must use energy at a slower rate than the cells of smaller organisms. Larger organisms live correspondingly longer. For every 10^4 that the mass increases, the heartbeat time decreases by 1/10 and the lifetime increases by 10x. This even holds for human adults compared to human newborns: the cells of a fetus use energy at the slow pace of an adult while it is still effectively an organ of its mother, but after birth it becomes a separate small creature and within about 36 hours all its cells have sped up to about twice that rate.

One stunning implication is that every mammal, no matter what its size, gets roughly the same number of heartbeats in a lifetime – about 1.5 billion.



The fractal nature of the human circulatory system.

For more details and references, see Primack and Abrams, *The View from the Center of the Universe* (2006), Chapter 8.

What We Already Know About Intelligent Aliens

Like us, aliens are likely to be made of the most abundant reactive elements – hydrogen, oxygen, carbon, and nitrogen – which we know have a uniquely complex chemistry. A recent discovery by Geoffrey West and his collaborators has revealed another way that aliens are likely to resemble us: they are likely to have similar circulatory systems, and therefore also to have similar rates of using energy and perhaps even similar lifespans.

The idea of size scales is the heart of this biological discovery. Cells of *all* plants and animals on Earth are about 10^{-3} cm – regardless of the size of the plant or animal. Since every cell needs nutrients, any large organism needs a circulatory system to get the nutrients to the cells and carry away the cells' wastes. The circulatory system is basically a network of tubes where each branch branches, and each of those branches again, down to the tiniest capillaries that supply individual cells. No matter what size scale you zoom in on, from the largest arteries to the smallest capillaries, the circulatory system looks pretty much the same. Any object that looks the same across size scales is called a "fractal."

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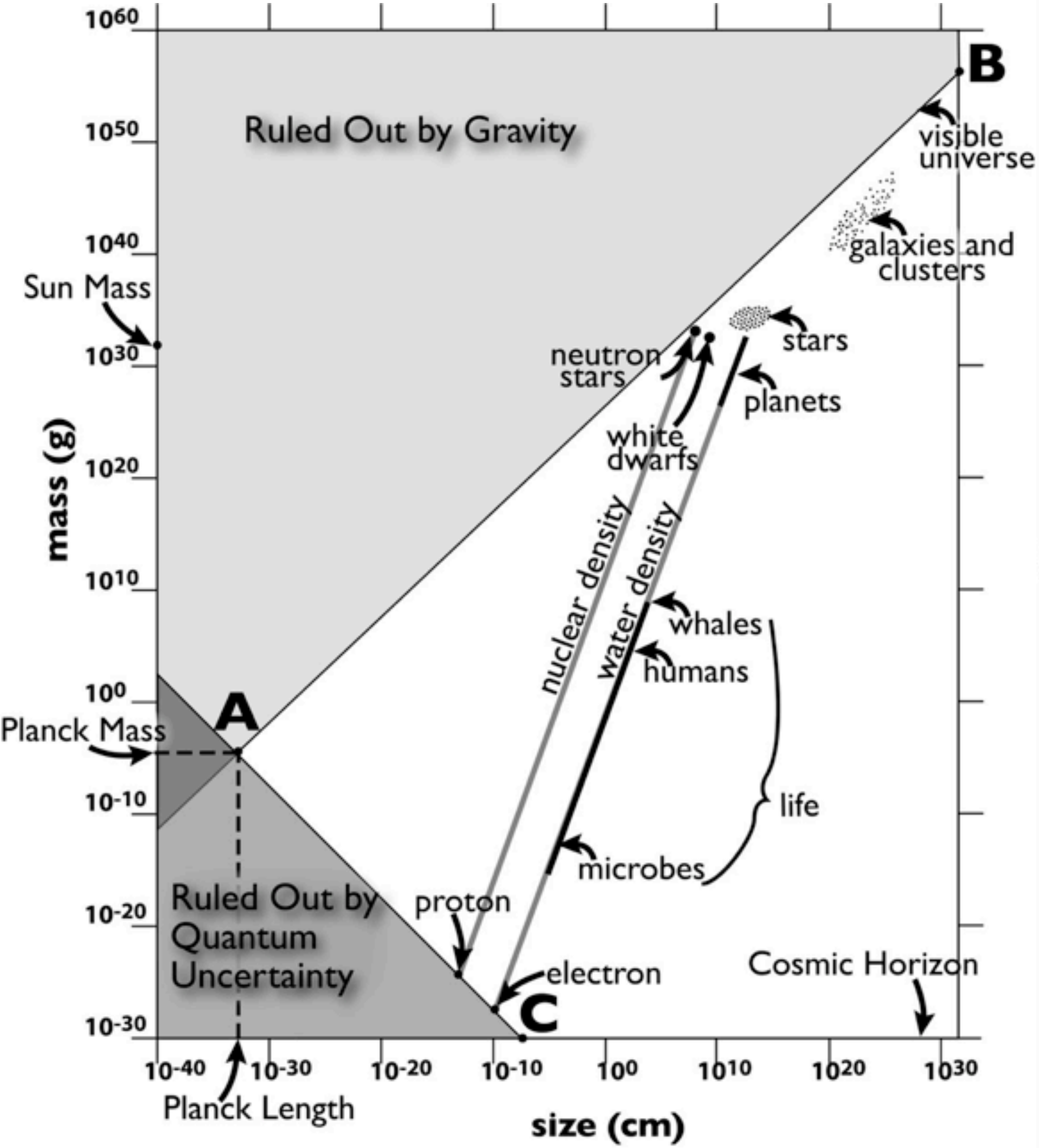
Any animal is likely to have a fractal circulatory system no matter what planet it originates on, and natural selection will probably control evolution everywhere, so the scaling laws and perhaps also lifespans among aliens may be similar to ours. Of course, it is also possible that genetic engineering may have replaced natural selection on worlds with alien intelligence, as may be happening on earth now.

The Wedge of Material Reality



Primack and Abrams, *The View from the Center of the Universe*

The **Planck Length**

$$l_{Pl} = \sqrt{\frac{hG}{2\pi c^3}} = 1.6 \times 10^{-33}\ \text{cm}$$

is the smallest possible length.

Here h is Planck's constant

$$h = 6.626068 \times 10^{-34}\ \text{m}^2\ \text{kg} / \text{s}$$

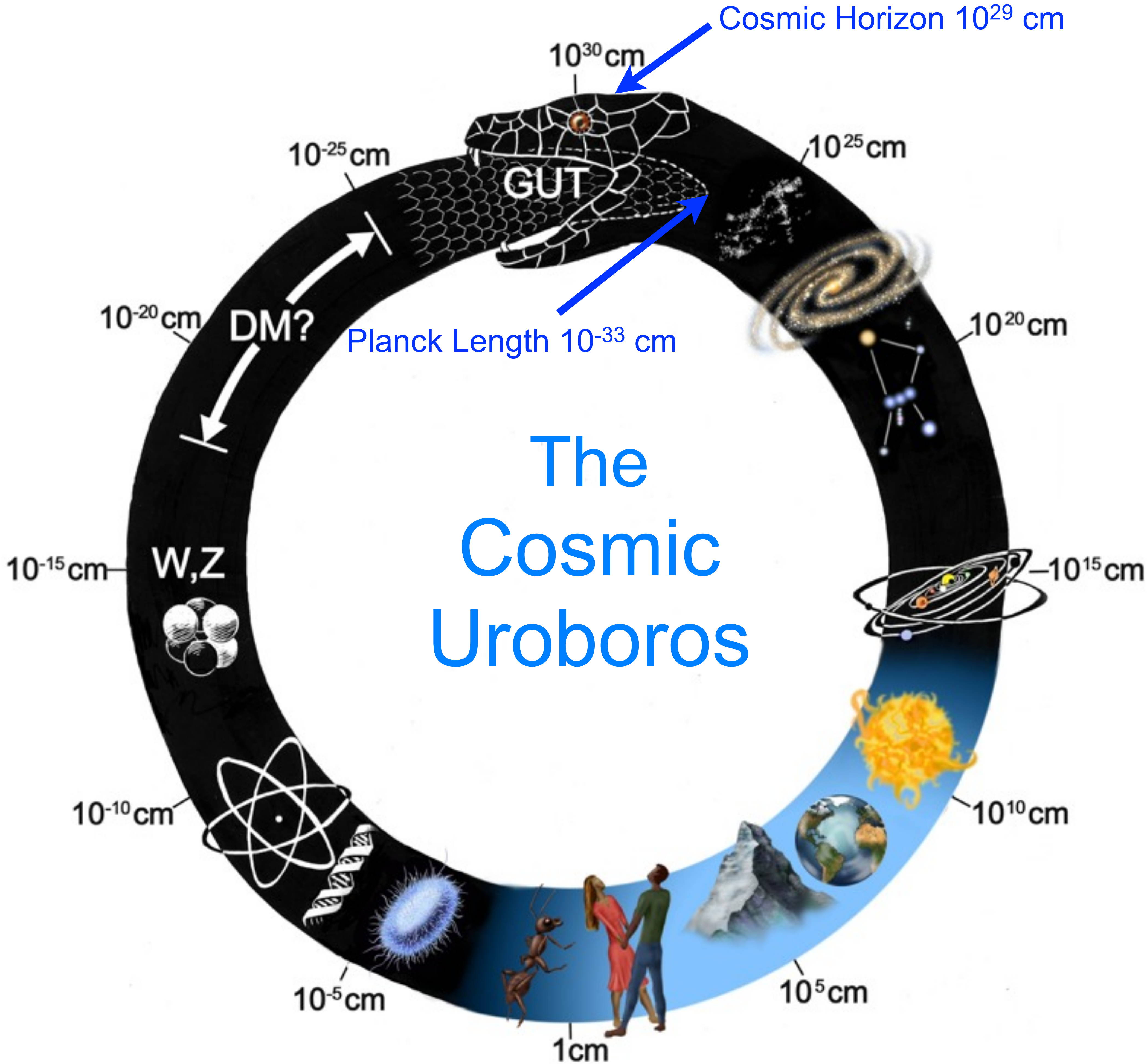
The Planck Mass is

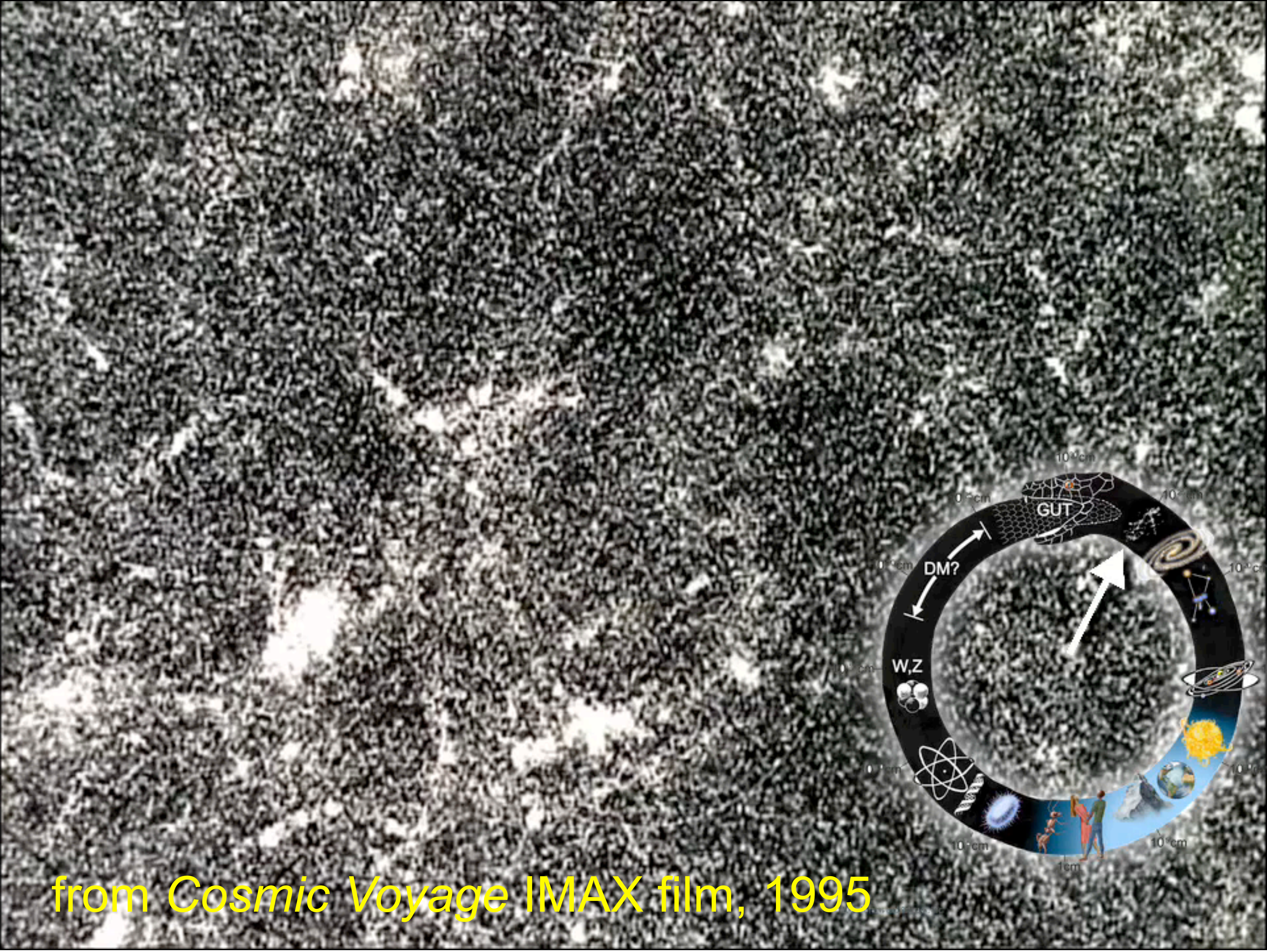
$$m_{Pl} = \sqrt{\frac{hc}{2\pi G}} = 2.2 \times 10^{-5}\ \text{g}$$

The Compton (i.e. quantum) wavelength $l_C = \dfrac{h}{2\pi mc}$

equals the Schwarzschild radius $l_S \approx \dfrac{Gm}{c^2}$

when $m = m_{Pl}$


Cosmic Horizon 10^{29} cm
10^{30} cm
10^{-25} cm
GUT
10^{25} cm
10^{-20} cm
DM?
Planck Length 10^{-33} cm
10^{20} cm
The Cosmic Uroboros
10^{-15} cm
W,Z
10^{15} cm
10^{-10} cm
10^{10} cm
10^{-5} cm
1cm
10^{5} cm

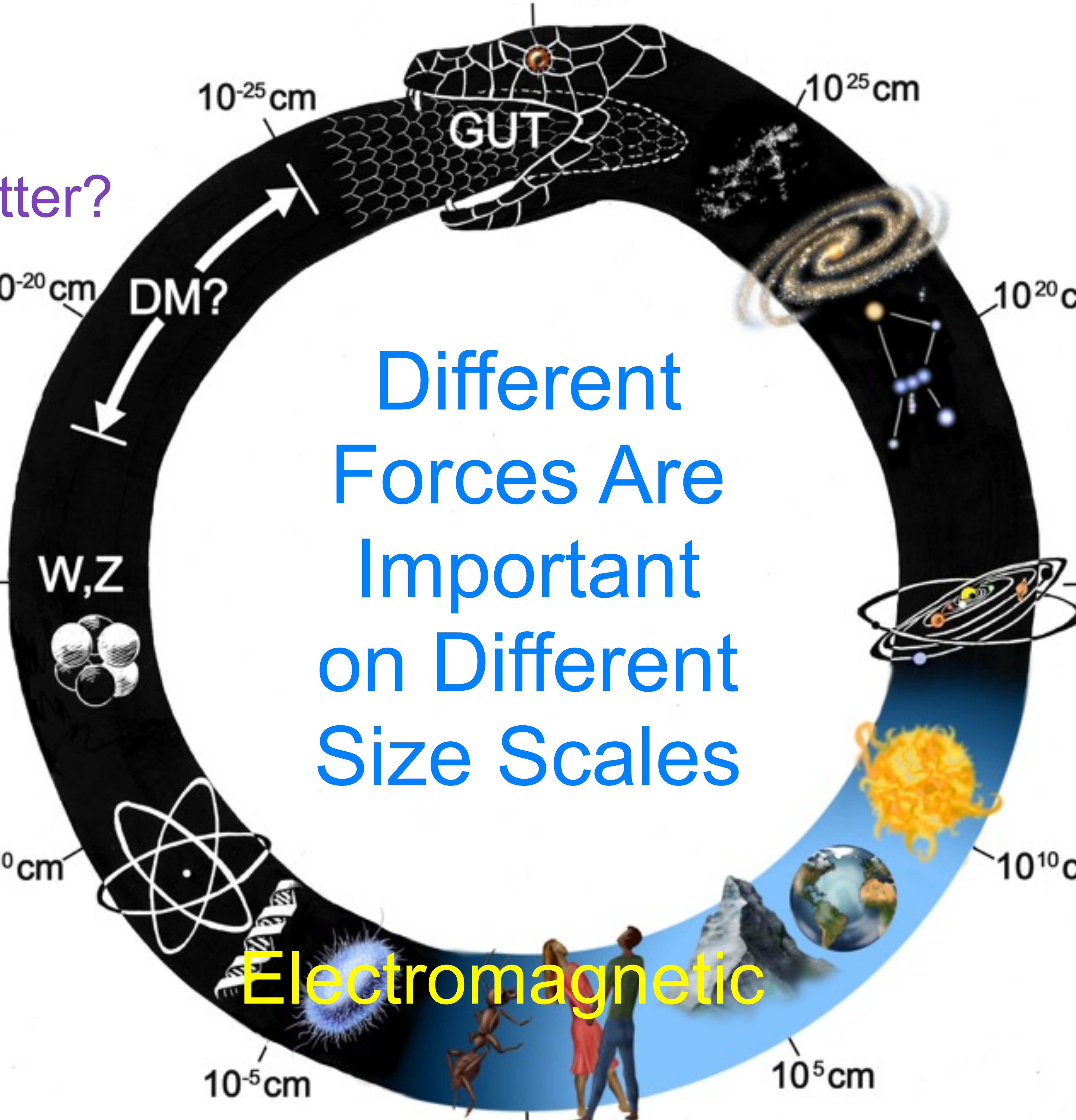


from *Cosmic Voyage* IMAX film, 1995

Superstrings?

Dark Matter?

Weak &
Strong



Different
Forces Are
Important
on Different
Size Scales

Electromagnetic

Gravitation

SIZE MATTERS!

SIZE MATTERS!

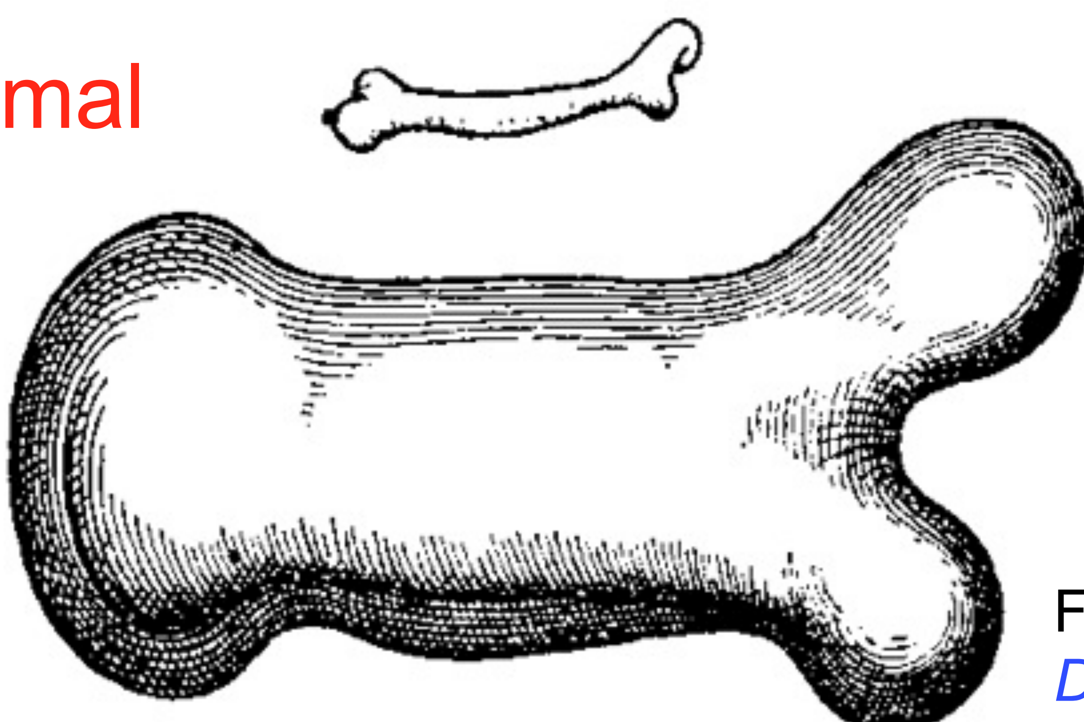
No animal could be 3 times its normal height and stay the same shape, simply scaled up.

If height increases 3 times,
strength of bones increases 3x3 = 9 times.
But weight increases 3x3x3 = 27 times.
Its weight would crush its bones!

That is why an elephant does not look like a large gazelle.

Bone of small animal

Bone of animal
3 times longer



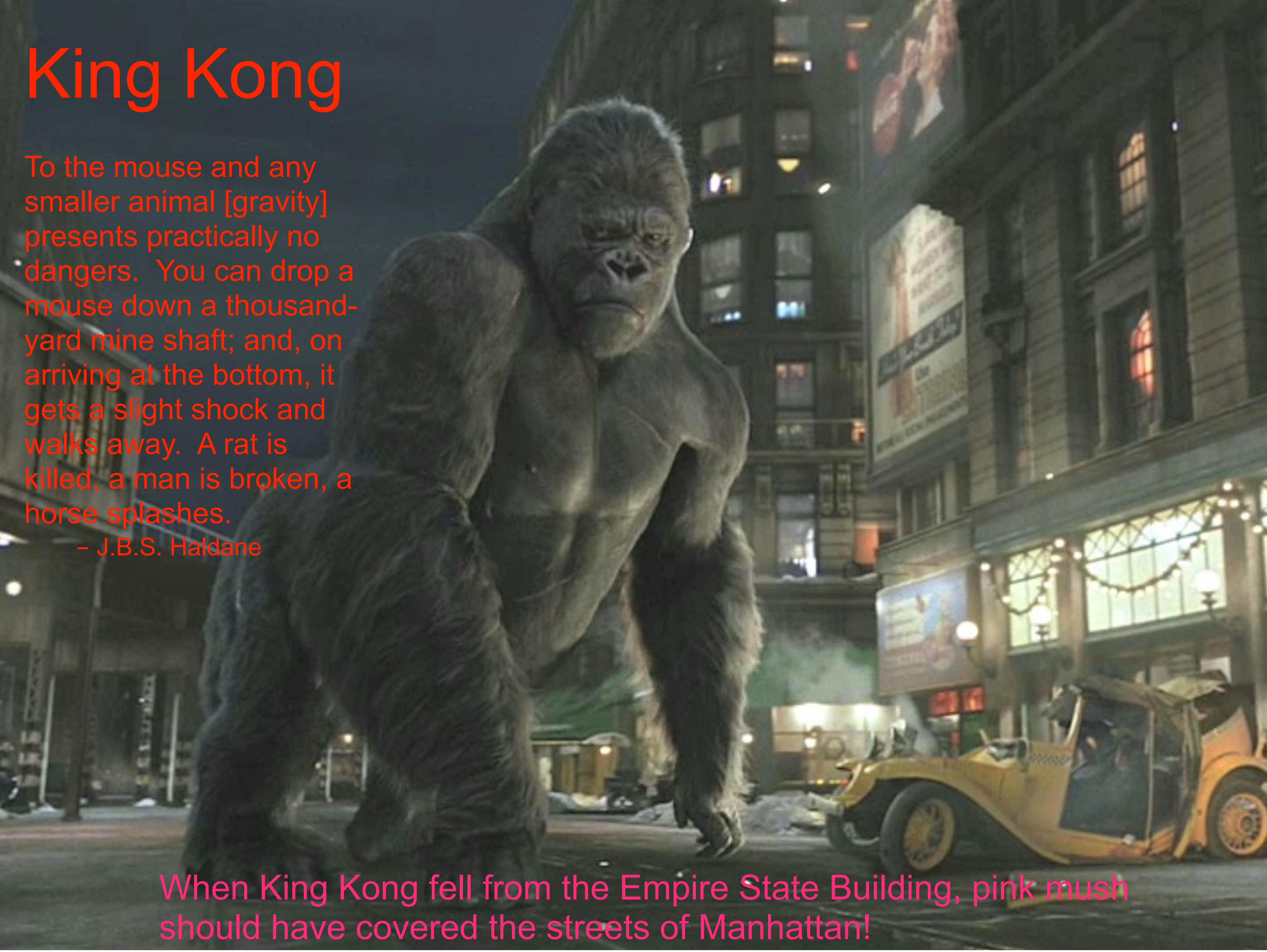
From Galileo's last book, *Discourses On Two New Sciences* (1638).

King Kong

King Kong

To the mouse and any smaller animal [gravity] presents practically no dangers. You can drop a mouse down a thousand-yard mine shaft; and, on arriving at the bottom, it gets a slight shock and walks away. A rat is killed, a man is broken, a horse splashes.

– J.B.S. Haldane



When King Kong fell from the Empire State Building, pink mush should have covered the streets of Manhattan!

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